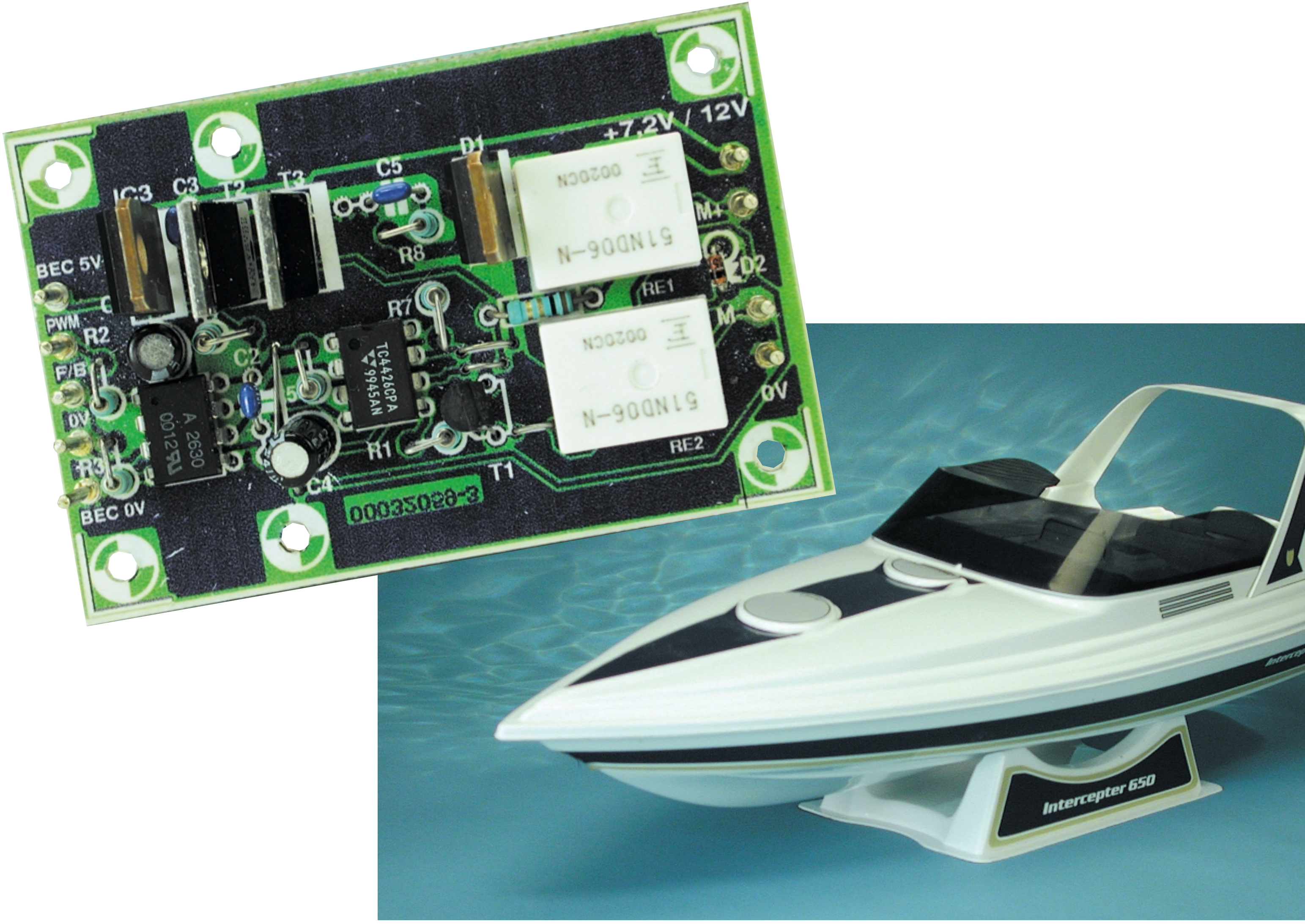
Speed Controller Duet (2)

part 2: construction, programming and the power units

Design by B. Stuurman

Part 1 presented an overview of the system. In part 2, we deal with the construction of the SpeedControl unit, user programming with a PC (via the RS232 interface) and finally the construction of the two power units: SpeedPower 1 and SpeedPower 2.



COMPONENTS LIST

Resistors:

R1,R4,R8,R13 = 10kΩ
R2 = 100kΩ
R3,R7 = 2kΩ2
R5,R6,R9-R12 = 1kΩ
R14,R15 = 560Ω
P1 = multiturn preset, vertical mounting (e.g., Bourns 3386W)

Capacitors:

C1 = 220pF ceramic, lead pitch 2.5 mm
C2 = 100µF 16V, radial
C3 = 100nF
C4,C5 = 18pF ceramic

Semiconductors:

D1 =zener diode 2V3
D2,D3 = high-efficiency-LED (3 mm) red
D4 = high-efficiency-LED yellow
D5 = high-efficiency-LED green
D6,D7 = BAT85
T1,T5 = BC547
T2,T3,T4 = BC557
IC1 =ST62T60BB6, programmed, order code **000070-41** (see Readers Services-page)

Miscellaneous:

S1 = pushbutton, make contact
X1 = 4MHz quartz crystal
Bz 1 = AC buzzer
Ferrite suppressor coil
PCB:
- in combination with SpeedPower1: order code **000070-5**;
- in combination with SpeedPower2: order code **000070-4**

(see Readers Services-page).

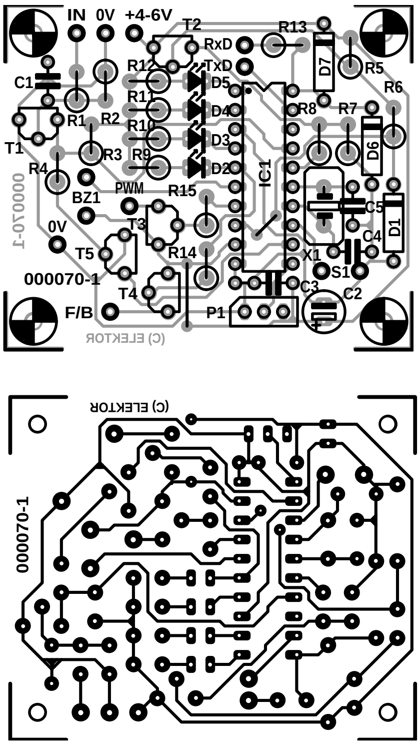


Figure 4. SpeedControl printed circuit board layout (scale 1:1)

SpeedControl construction

The printed circuit board for the SpeedControl unit is shown in **Figure 4**. For economic reasons, this board is only available in combination with one of the two SpeedPower boards (see the Components List), so the first task is to saw apart the two boards (if you so desire).

If you work calmly and carefully with a fine-tipped soldering iron and keep to the components identified in the Components List, you shouldn't have any problems assembling the circuit board. A servo extension cable that has been cut in two can be used for the connecting cable. It is a good idea to fit a ferrite toroidal core onto the cable to the receiver, since this will isolate the circuit from high frequency signals from the receiver, and the remaining length of the cable will not degrade signal reception.

When everything is finished, wait a bit before placing the microcontroller in its socket. First connect the SpeedControl to an adjustable power supply with a range of 0–6 V, and connect a voltmeter between 0 V and a needle inserted into the connection for the reset signal at the IC socket. Slowly increase the applied voltage. The reset signal should remain Low until around 3.7 V, where it should immediately go High. From around 3.75 V onwards, it should track the supply voltage. If this is all OK, you

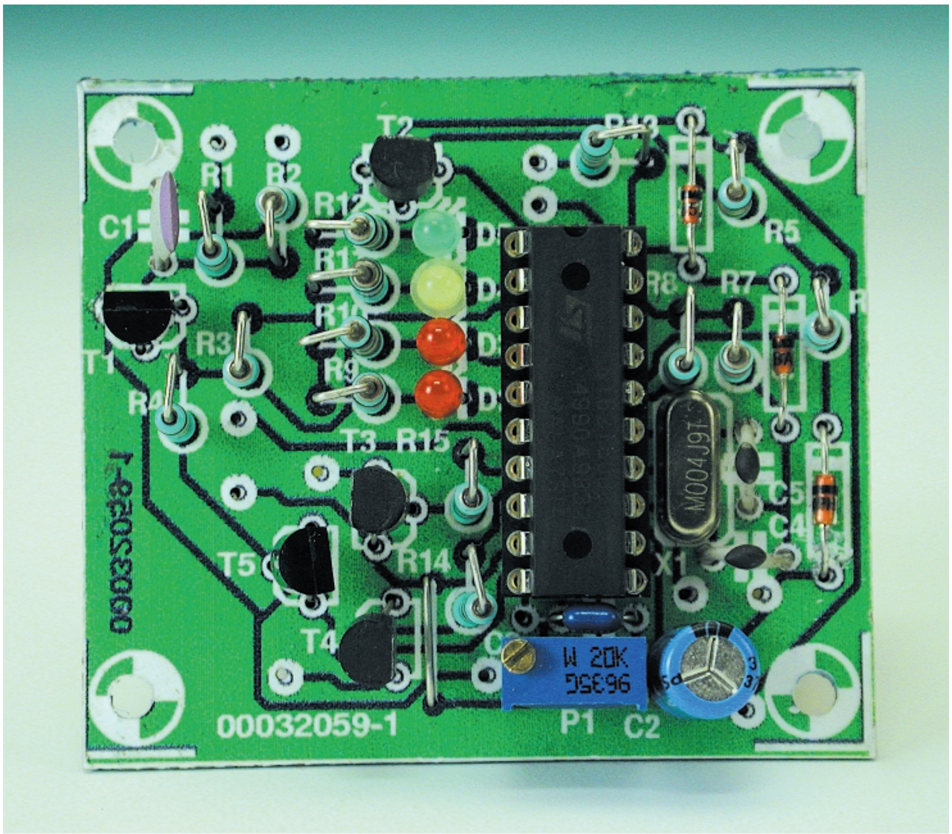


Figure 5. Fully assembled SpeedControl unit.

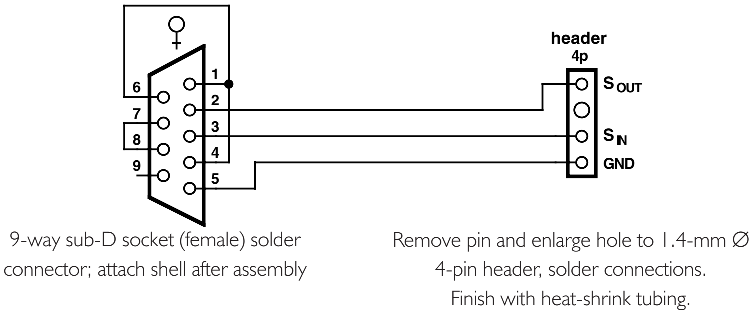

header
4p
S OUT
S IN
GND
1
2
3
4
5
6
7
8
9
9-way sub-D socket (female) solder connector; attach shell after assembly
Remove pin and enlarge hole to 1.4-mm Ø 4-pin header, solder connections. Finish with heat-shrink tubing.

Figure 6. RS232 cable for communicating with a PC.

can insert the microcontroller in its socket. The ready-made circuit board for the SpeedControl is shown in **Figure 5**.

Programming

Before going any further, it's helpful if you first match the SpeedControl to the transmitter using the three-point timing setup, and in particular the setup described in Example 2 of the first part of this article. Once this has been done, you can test the operation of the 'forw/back' output.

After this test, the receiver and the SpeedControl can be switched off. Set trimpot P1 to the 'speed' position and hold the pushbutton down while switching on the power. Now you can test the operation of the trimpot. Its behaviour should be essentially the same as that of the control stick of the transmitter.

If no programming has been carried out, default values are used. The microcontroller copies these value from the ROM to the EEPROM when it is first started up. A 'virgin' EEPROM cell contains either 00h or FFh. After the values have been copied, the 'test cell' contains 08h, so the program knows that the EEPROM has already been written. In the descriptions of the commands, the default values are shown in parentheses.

A special cable is needed to allow the SpeedControl to communicate with a PC. The schematic of this cable is shown in **Figure 6**. The three loopback connections trick the RS232 interface into being able to function with only three leads ('gnd', 'in' and 'out'). In addition, you will need a terminal emulator, such as the Windows accessory HyperTerminal program. If you don't use Windows, an 'old-timer' communications program, such as ProComm, is perfectly usable. Set the protocol parameters to 19200 baud, 7 data bits, no parity and 2 stop bits. With HyperTerminal, you can save these settings on the desktop under the name 'Speed.ht' (for example). In our case, the new settings took effect only after HyperTerminal had been stopped and then restarted via Speed.ht.

In order to enter the programming mode, you must set the trimpot to the 'program' position and then switch on the power while pressing the pushbutton. The SpeedControl unit will then announce itself with the message 'command?' on the PC monitor. Now you can enter commands. If an incorrect command or incorrect parameter is entered, a beep is generated and a message appears on the screen. You can exit this situation by pressing the Escape key. If you type the command '?' followed by the Enter key, the command set is displayed as illustrated in **Figure 7**. Only lower-case letters may be used for entering commands. If the parameter is omitted, the currently active setting is displayed.

Commands

reptest (on) This switch command enables or disables testing the repetition interval (pulse rate). Disable this test only if the repetition interval of the transmitter is highly unstable. Note that this command disables the test, so to restore the original setting, the command must be issued twice. This applies to all switch commands!

cutoff [parameter] This command is used to set or disable the cutoff voltage. This is indispensable if the supply voltage for the receiver, servos and SpeedControl is taken from the BEC of a power unit, so that there is no separate battery for the receiver. When the supply voltage drops below the set-point value, the motor voltage is switched off. The power supply to the motor can be restored by putting the control stick in the neutral position, and it will remain on until the voltage again drops below the set-point value. In general, the cutoff voltage is referenced to the full-load battery voltage, for which a value of 0.7 V per NiCd cell is used (Sub-C, 1500–2000 mAh).

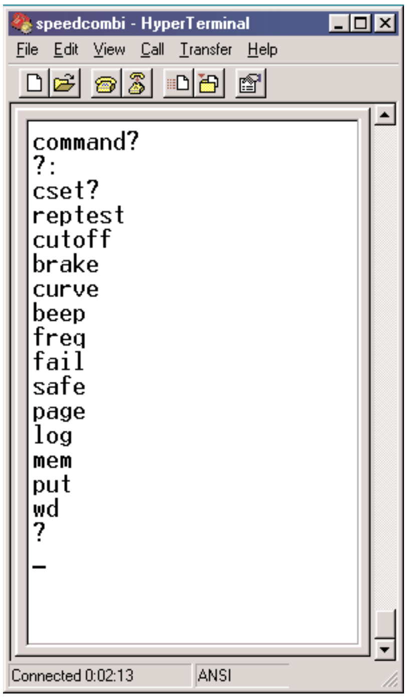
brake [parameter] The 'brake' command is intended for electric gliders with folding propellers that are fitted with a SpeedPower 2 unit. As soon as the control stick (or the trim) is set to the 'reverse' position, the brake FET is activated after a set time delay. 'Reverse' to 'forward' always has priority.

curve (linear) This switch command alternates between a linear and an exponential power curve. In the latter case, the amount of power supplied to the motor is a better match to the position of the control stick.

beep (high) This sets the volume of the beep to 'loud' or 'soft'.

freq [parameter] (2 kHz) This allows the frequency of the PWM signal to be set to four different values.

fail [parameter] (1 s) The combination of this command and the 'safe' command forms the 'fail-safe' provision of the SpeedControl. The 'fail' command can be used to specify the maximum interval allowed for receiving no pulses (or bad pulses) before reducing the motor power to zero.



```
command?
?:
cset?
reptest
cutoff
brake
curve
beep
freq
fail
safe
page
log
mem
put
wd
?
_
```

Figure 7. The SpeedControl command set.

safe (resume) The options for this command are 'resume' and 'go neutral'. If the motor power has been set to zero in response to a 'fail' condition and the 'resume' option is selected, normal operation will be resumed as soon as control pulses are again received. If the 'go neutral' option is selected, the control stick must first be set to the neutral position before normal operation is resumed.

log (off) If 'log' is active, bad pulses are recorded in the 'logbook'. This is a 16-bit counter that provides an indication of the reliability of the link. The logging function costs a lot of extra time in the controller, so it should normally be disabled.

Diagnostic commands

wd (on) This can be used to enable or disable the digital microcontroller's watchdog timer. If the watchdog times out, the microcontroller is reset. When the watchdog is disabled, the command processor in the main program loop is enabled and we can examine all memory locations in the microcontroller and modify them as desired.

mem [parameter] (off) This command, followed by a hexadecimal address, causes the content of the selected memory location to be displayed on the screen, updated approximately three times per second (exit with the Escape key).

put [parameter] The parameter byte is written to the memory location specified by the 'mem' command.

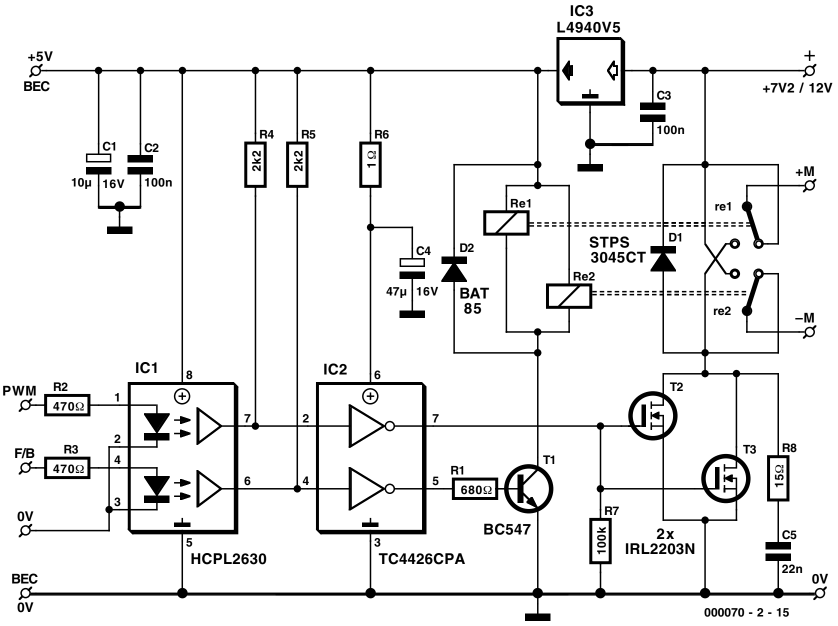


Figure 8. Schematic diagram of the SpeedPower 1.

page [parameter] 0 = EEPROM page 0, 1 = EEPROM page 1, 2 = RAM page 2.

The diagnostic commands can be used to restore the default values. This is done as follows. First enter 'mem 00' to select memory address 00h. Next, enter 'page 0' to select EEPROM page 0, and then enter 'put 00' to write the byte 00h to that address. Complete each entry with the Enter key. When the SpeedControl is again switched on, the default values will again be written to the EEPROM.

SpeedPower 1

The schematic diagram of the SpeedPower 1 unit, which has forward/reverse capability, is shown in **Figure 8**. The 5-V voltage regulator (IC3), which also supplies power to the BEC, is a low-drop type that can supply 1.5 A. With

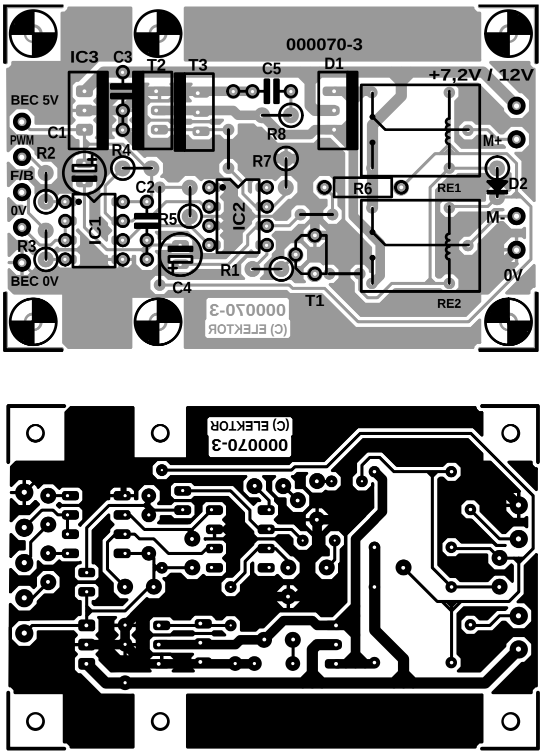


Figure 9. Printed circuit board layout for the SpeedPower 1.

COMPONENTNS LIST

SpeedPower 1

Resistors:
R1 = 680Ω
R2,R3 = 470Ω
R4,R5 = 2kΩ2
R6 = 1Ω
R7 = 100kΩ
R8 = 15Ω

Capacitors:
C1 = 10µF 16V radial
C2,C3 = 100nF
C4 = 47µF 16V radial
C5 = 22nF

Semiconductors:
D1 = STPS3045CT
D2 = BAT85
T1 = BC547
T2,T3 = IRL2203N
IC1 = HCPL2630
IC2 = TC4426CPA
IC3 = L4940V5

Miscellaneous:
Re1, Re2 = relay, Fujitsu 51ND06-N (Conrad Electronics #505099-11)
PC1-PC9 = solder pin
PCB, order code **000070-5** (in combination with SpeedControl – see Readers Services page)

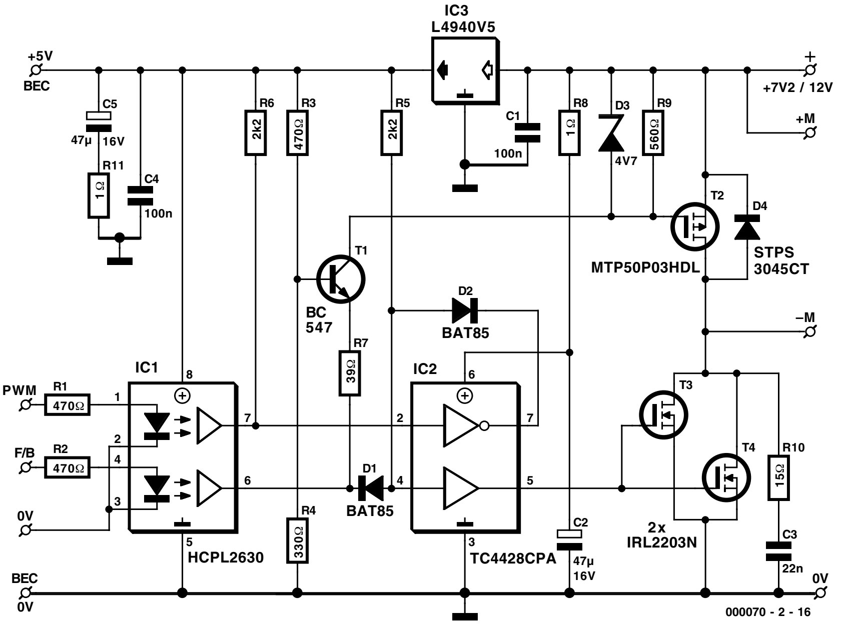


Figure 10. Schematic diagram of the SpeedPower 2.

two standard servos, the average current consumption from the BEC is around 150 to 250 mA, but if reception is lost and the servos start to jitter, the current consumption can rise to as much as 1.2 A, and the receiver must continue to work reliably under these conditions. The PWM and 'for/back' signals are electrically isolated by a dual digital optocoupler (IC1). IC2 is a dual inverting driver for power MOSFETs. Each output can source or sink 1.5 A, and the voltage can range from 0 V on the ground lead (pin 3) to the supply voltage (pin 6). The inputs are TTL compatible. One driver output (pin 7) is used to control two power MOSFETs wired in parallel (T2 & T3), while the other output controls a switching transistor (T1) that activates the relay. A pair of Schottky diodes in a dual package is connected across the MOSFET outputs to handle flyback currents, along with the 'snubber' network (R8 & C5) that protects the MOSFETs. The circuit is designed such that the motor cannot run in the absence of an input signal.

Figure 9 shows the printed circuit board for the SpeedPower 1. This is supplied in combination with the SpeedControl circuit board, and it can be separated from the latter board if desired. The same remarks apply to the assembly of this board as for the SpeedPower board. The current-carrying tracks are laid out extra wide, and if necessary they can be electrically 'beefed up' by soldering lengths of copper wire on top.

Finally, fasten the interconnecting cables and BEC cable. If the distance between the power unit and the receiver is greater than 20 cm, it is a good idea to fit a ferrite toroidal core on the BEC cable, close to the receiver.

SpeedPower 2

Figure 10 shows the schematic diagram of the SpeedPower 2 unit, which includes a brake FET. The power MOSFET driver IC2 is a different type than the driver used in the SpeedPower 1 unit; it has an inverting and a non-inverting stage. When 'for/back' is not active, output pin 6 of the optocoupler (IC1) is High, which blocks diode D1. The 'PWM' signal reaches the non-inverting driver, which controls the power MOSFETs, via the inverting driver and diode D2. When 'for/back' is active, output pin 6 of the optocoupler is Low, so that diode D1 conducts. Input pin 4 of the optocoupler remains Low, and consequently also the gates of T2 and T3.

The base of T3 is connected to a fixed voltage of 3 V. When 'for/back' is Low, the emitter of T1 is connected

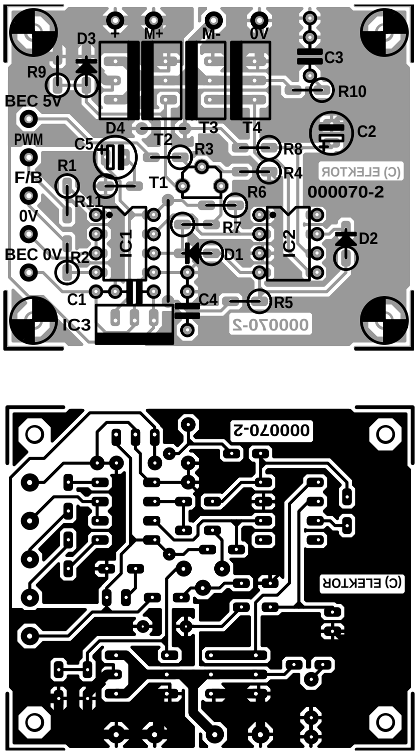


Figure 11. Printed circuit board layout for the SpeedPower 2.

COMPONENTS LIST
SpeedPower 2

Resistors:
R1,R2,R3 = 470Ω
R4 = 330Ω
R5,R6 = 2kΩ2
R7 = 39Ω
R8,R11 = 1Ω
R9 = 560Ω
R10 = 15Ω

Capacitors:
C1,C4 = 100nF
C2,C5 = 47µF 16V radial
C3 = 22nF

Semiconductors:
D1,D2 = BAT85
D3 = zener diode 4V7
D4 = STPS3045CT
T1 = BC547
T2 = MTP50P03HDL
T3,T4 = IRL2203N
IC1 = HCPL2630
IC2 = TC4428CPA
IC3 = L4940V5

Miscellaneous:
PC1-PC9 = solder pin
PCB, order code **000070-4** (in combination with SpeedControl – see Readers Services page)

to ‘ground’ via R7. T1 then acts as a constant-current source, and its collector sinks 20 mA. This pulls the gate of MOSFET T2 towards ground until Zener diode D3 starts to conduct. A stable state then arises, in which T2 ‘shorts out’ the motor with a resistance of around 20 mΩ. This is the ‘brake’ state. When ‘for/back’ stops being active, T1 cuts off and the gate of T2 is again pulled to the source level, which causes T2 to cut off.

If the brake state does not work effectively, the value of R9 may be increased as necessary, up to around 1 kΩ.

The printed circuit board designed for the SpeedPower 2 unit is shown in **Figure 11**. This is also provided in combination with a SpeedControl board. Here again, the relevant printed circuit tracks have been kept as wide as possible, but it is recommended to reinforce the connections between T2–T4 and the M+ and M– connections by soldering copper wires on top.

Both power units should be initially tested using a power supply that is current limited to two ampères. After this, you can connect them to the battery pack, but be careful on account of the high currents that can flow. There is a risk of fire in case of a short circuit, and explosions are even possible.

And finally: the controls are in your hands!

(000070-2)

Power MOSFETs

Due to the low nominal value of the supply voltage (7.2 V), it is not possible to use ordinary MOSFETs in the power units without resorting to a lot of trickery. The threshold voltage of such devices, $V_{gs(thresh)}$, lies at around 4 V, and the saturation resistance $R_{ds(on)}$ shown in the data sheets is only achieved at a voltage of 7 to 8 V. With logic power MOSFETs, the threshold voltage is much lower (2 to 2.5 V), and the on resistance is already extremely low at ‘logic voltage’ levels (5 V). The price that must be paid for this is that the gate capacitance is much greater than that of a standard power MOSFET. This means that more power is needed for the (PWM) drive signal, which is why special driver ICs are used in the power units. We have selected three types of logic power MOSFETs that are very well suited for use in the power units. They are listed in the accompanying table.

All three of these power MOSFETs have a TO-220 package. This type of package can dissipate 1 W without supplementary cooling. With a small cooling fin (a piece of 2-mm thick aluminium, around 10 × 27 mm), this can be increased to 2 W. The maximum continuous current that a single MOSFET can handle is thus the amount that produces a dissipation of 2 W. For the IRL2203, this is $\sqrt{(2/0.01)}$ = 14 A. A power unit with two IRL2203s can thus handle a continuous current of 28 A. The highest current level (36 A) can be achieved using a pair of IRL3803s, but these are significantly more expensive. Don’t forget that we’re talking about continuous current here; considerably higher currents can be handled for short intervals. The table shows the current handling capacities of power units fitted with pairs of the listed types of power MOSFETs, both continuously and for a 30-second interval.

MOSFET type	**$R_{DS(on)}$ V_{gs}=5 V**	**$R_{DS(on)}$ V_{gs}=10 V**	**$I_{(cont)}$ 2 pieces**	**$I_{(30s)}$ 2 pieces**
BUZ100L	18 mΩ	12 mΩ	26 A	39 A
IRL2203	15 mΩ	10 mΩ	28 A	42 A
IRL3803	9 mΩ	6 mΩ	36 A	54 A

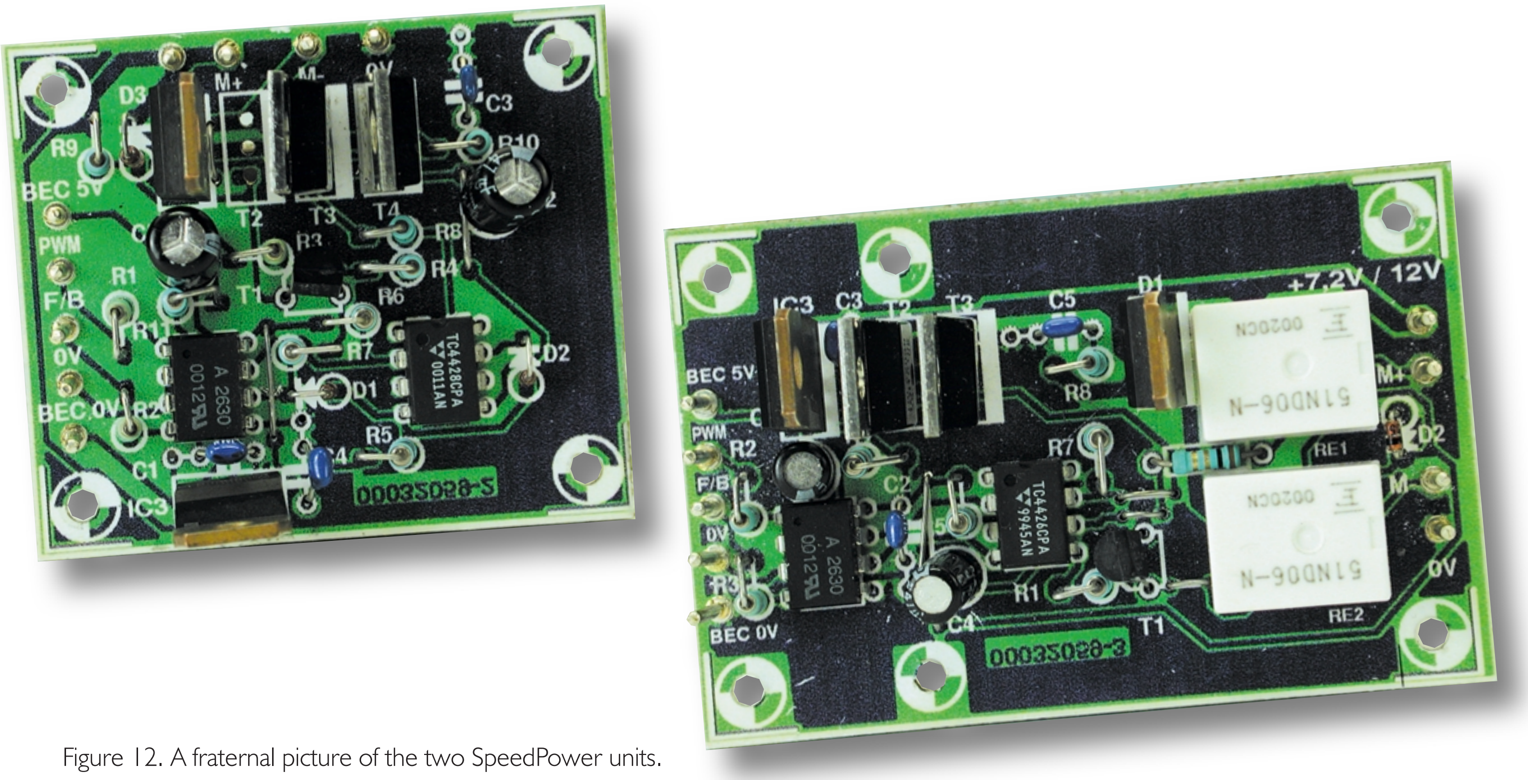


Figure 12. A fraternal picture of the two SpeedPower units.